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(54) **Sensor systems**

(57) A pressure sensing system for compensating the actual pressure value sensed by a pressure transducer 1 uses a CMOS microprocessor 3 to calculate initial correction coefficients for the particular transducer being used from four combinations of pressure sensed by the transducer and temperature sensed by a temperature sensor 2. The correction coefficients are then stored in a memory and used for correcting the sensed pressure values by the microprocessor according to variations in temperature. The microprocessor also programmes analogue compensating circuitry 4 via its input/output port lines to maximise the voltage swing input to the microprocessor by providing coarse corrections to the gain and offset of the signal from the pressure transducer.

The object is to simplify the process of calibration, to remove the need for external adjustments of a transducer and to allow changes of transducer type without the need for external adjustments.

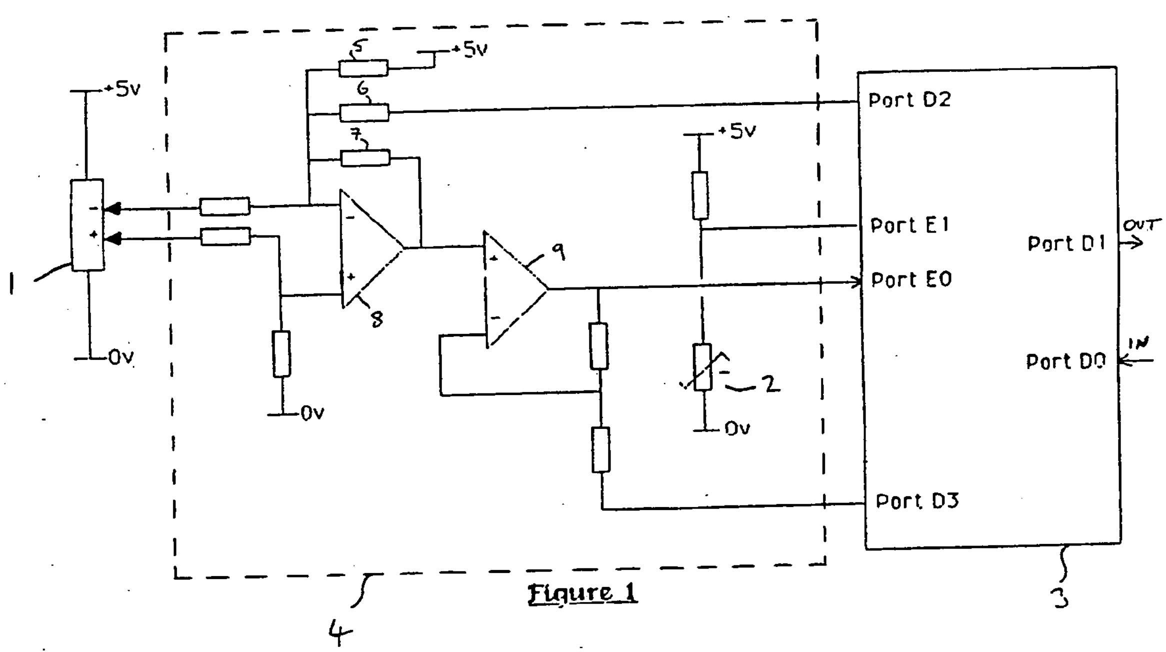

Figure 1

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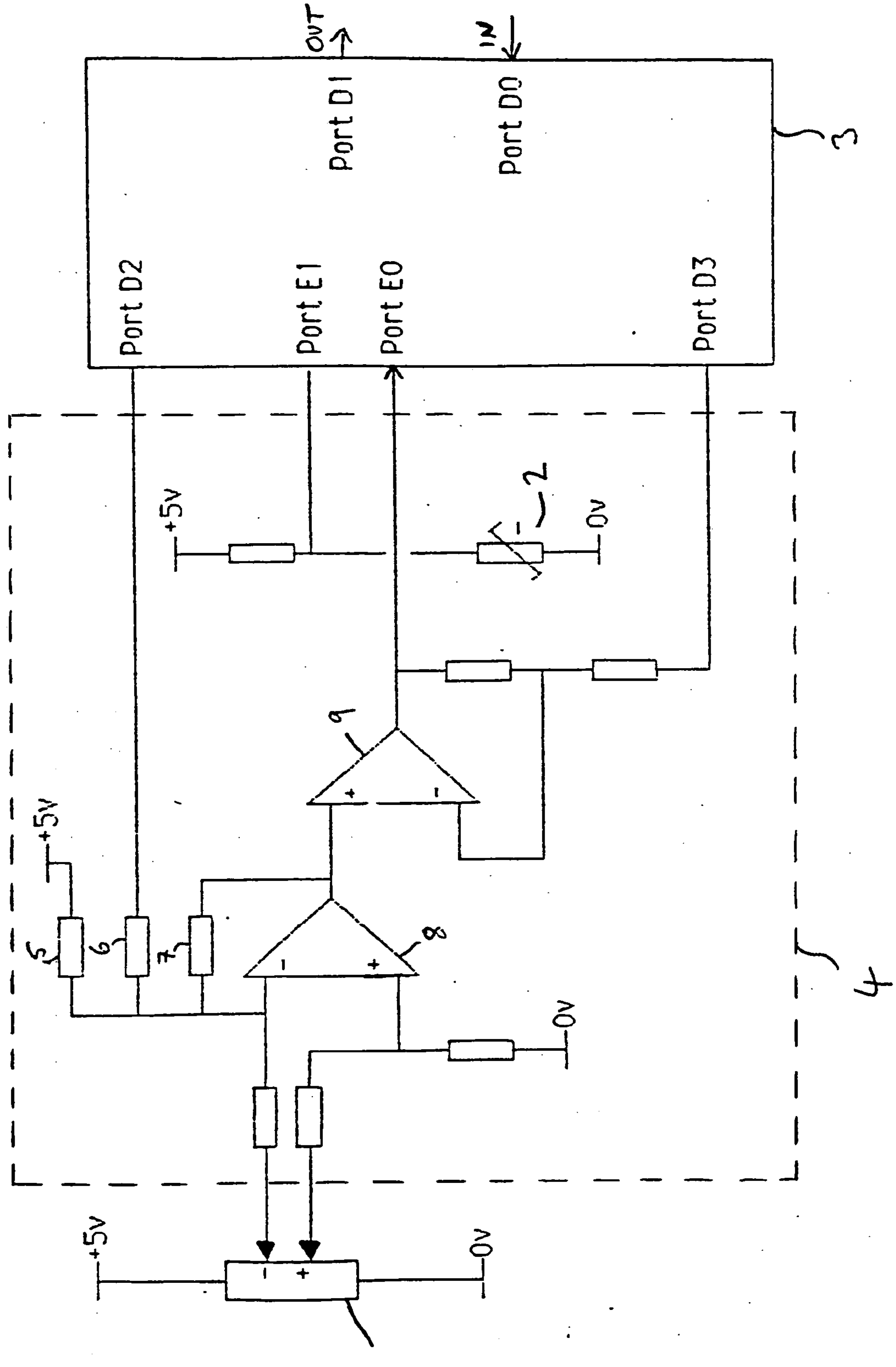
OUT
IN
Port D1
Port D0
3
Port D2
Port E1
Port E0
Port D3
+5v
2
0v
9
+5v
5
6
7
8
0v
4
+5v
0v
1

Figure 1

SENSOR SYSTEMS

This invention relates to sensor systems of the type where one or more sensor elements interface with a CMOS microcomputer, and more particularly, though not exclusively to such systems for sensing pressure within an engine management unit for an automobile.

Pressure sensing elements are used to provide an output signal indicative of the sensed pressure. The output signal is generally defined by two parameters - the offset which is the level of the output signal at a reference sensed pressure level, and the gain which is the rate at which the output signal increases for an increase in sensed pressure. Both of these parameters suffer from errors. One reason for such variations is the device to device differences caused by manufacturing fluctuations. Another cause of errors is the effect of temperature on the sensing elements.

Typically, the offset can vary between 0 and 35 mV and full scale output span can vary between 45 and 90 mV (from a 3V supply). Thus the output range that has to be allowed for is from 0 to 125 mV, and for a device with a span of only 45 mV, the output only covers 45/175 or 36% of the range.

The temperature has two distinct effects, one on the offset and one on the span. The first is a shift of the whole characteristic and the second is a rotation of the transfer function about some point. The worst case temperature coefficient of span is $-0.22\%/^{o}C$, thus giving a 36% change over the full range of $-40^{o}C$ to $+125^{o}C$; however for changes from ambient the figure is 22%. The typical offset is $+15\mu V/^{o}C$ giving 1.5mV change over $100^{o}C$ in a minimum span of 45 mV; this represents 3%.

If these two variations are combined, it can be seen that the worst case variations can be considerable, resulting in a worst case of less than 27% of the range being usable.

Such gain and offset variations have hitherto required external software to be specifically tailored to correct for individual sensing element variations. External hardware adjustments have had to be made to compensate for device differences, and further external adjustments have had to be made if the sensing element is replaced by another one of the same type or same series.

The present invention is therefore intended to simplify the process of calibration and correct for offset and gain in sensing elements interfacing with CMOS microcomputers, to remove the need for external adjustments for each sensing element and to allow changes in sensing element type without requiring external adjustments.

Accordingly, the invention provides a sensor system comprising one of more sensing elements providing an output signal corresponding to a sensed parameter, means for calculating correction coefficients, a memory for storing said correction coefficients and a CMOS microprocessor for receiving said output signal, for calculating fine trim correction factors for both the gain and the offset of the sensing element(s) using said correction coefficients and for providing a corrected output signal.

In a preferred embodiment of the invention, the memory is an EEPROM. Said means for calculating said correction coefficients is preferably said CMOS microprocessor. Preferably, the sensor system further includes compensating means coupled between said sensing element(s) and said CMOS microprocessor for providing a coarse trim of both the offset and the gain of the output signal from the sensing element(s) to the CMOS microprocessor. The compensating means conveniently includes means for providing one of a plurality of discrete offsets and one of a plurality of gains, the desired combination of offset and gain being programmed by the CMOS microprocessor.

The sensor system may be used in an engine management unit for automobiles in which case the sensing element(s) is/are pressure transducers. The correction coefficients may then be calculated by the CMOS microprocessor from four combinations of measured values of pressure and temperature.

The gain and offset of the compensating means is preferably programmed less frequently than the frequency of pressure sensing by the CMOS microprocessor according to measured values of temperature.

The invention will now be more fully described by way of example with reference to the drawing which is a block diagram of a sensor system for use in an engine management unit for an automobile.

The engine management unit includes a pressure transducer 1, such as MPX100A manufactured by Motorola Inc. for sensing the actual pressure and a temperature sensor 2 for measuring the ambient temperature. The pressure readings from the transducer 1 are then corrected by a microcomputer 3 such as that manufactured by Motorola Inc under the designation MC68HC11A8.

The signal indicative of the actual measured pressure from the transducer 1 passes via analogue compensating circuitry 4 to an analogue input of the microcomputer 3 at Port E0. The signal indicative of the ambient temperature from sensor 2 is input to the microcomputer 3 at Port E1. The analogue compensating circuitry 4 is controlled by the microcomputer 3 via input/output lines connected to Ports D1 and D3.

The microcomputer 3 produces the digital equivalent of the measured pressure, compensated for ambient temperature variations at output Port D1. In order to perform the calculations required to produce the digital equivalent of the measured pressure, the system must first be calibrated for the particular pressure transducer 1 being used in order to establish the coefficients used in the calculations. These coefficients are then stored in the EEPROM forming part of the microcomputer 3 and do not have to be recalculated again for the particular transducer 1 being used.

It will be appreciated from what was described above that the transducer needs correcting for four variations:

(i) unit to unit variation in sensitivity;
(ii) unit to unit variation in offset;
(iii) temperature effect on sensitivity (also varies from unit to unit);
(iv) temperature effect on offset (also varies from unit to unit)

Thus, a first order equation can be written:

$$P = k_4x+k_3+Tk_1x+Tk_2$$

This can be rearranged as follows:

$$P = x(k_4+Tk_1) + (k_3+Tk_2)$$ where

P = Pressure after compensation
x = raw input pressure value
T = temperature
K_1 = temp span correction coefficient
K_2 = temperature coefficient of offset
K_3 = offset at T=O
K_4 = fine scale factor

Since the rate of change of temperature is typically two or more orders of magnitude less than the rate of change of pressure, Tk_1 and Tk_2 need be computed less frequently than P and this gives rise to two levels of calculation. Considering the equation in the form:

$$P = mx+c$$

the background calculations, relating to change in the ambient temperature, become:

$$m = k_4 + Tk_1$$

$$c = k_3 + Tk_2$$

and the foreground calculation, correcting the actual measured pressure, is reduced to:

$$P = mx+c$$

requiring only one multiplication and one addition in the more frequent part of the calculations.

For the calibration of the unit, the four correction coefficients k_1 to k_4 must be found. This requires four tests; one at each of the combinations of two pressure values and two temperature values.

The optimum points for these will be somewhere between the limits and the most common operating points to get the lowest errors when taking truncation errors in the arithmetic and linearity errors in the transducer into account.

(i) At T_0 and P_0, x_a is measured and the equation becomes:

$$P_0 = k_4x_a+T_0k_1x_a+k_3+T_0k_2 \qquad (a)$$

(ii) At T_0 and P_1, x_b is measured:

$$P_1 = k_4x_b+T_0k_1x_b \; T_0k_2 \qquad (b)$$

(iii) At T_1 and P_0, x_c is measured:

$$P_0 = k_4x_c+T_1k_1x_c+k_3+T_1k_2 \qquad (c)$$

(iv) At T_1 and P_1, x_d is measured:

$$P_1 = k_4x_d+T_1k_1x_d+k_3T_1k_2 \qquad (d)$$

Note that if a gauge transducer is being used, the signal is the opposite sense to the pressure, so the pressure should be considered as being positive from atmospheric even though it is going down.

From (a) and (b) we get:

$$P_1-P_0 = (k_4+T_0k_1)(x_b-x_a)$$

thus $k_4+T_0k_1 = \dfrac{(P_1-P_0)}{(x_b-x_a)}$

and so $k_4 = \dfrac{(P_1-P_0)}{(x_b-x_a)}-T_0k_1$ (e)

From (c) and (d) we get:

$$P_1-P_0 = (k_4+T_1k_1)(x_d-x_c)$$

thus $k_4+T_1k_1 = \dfrac{(P_1-P_0)}{(x_d-x_c)}$

and so $k_4 = \dfrac{(P_1-P_0)}{(x_d-x_c)}-T_1k_1$ (f)

From (e) and (f) we get:

$$\frac{(P_1-P_0)}{(x_b-x_a)}-T_0k_1 = \frac{(P_1-P_0)}{(x_d-x_c)}-T_1k_1$$

thus $T_1k_1 - T_0k_1 = \dfrac{(P_1-P_0)}{(x_d-x_c)} - \dfrac{(P_1-P_0)}{(x_b-x_a)}$

and so

$$k_1 = \frac{\dfrac{(P_1-P_0)}{(x_d-x_c)} - \dfrac{(P_1-P_0)}{(x_b-x_a)}}{(T_1-T_0)}$$

Thus k_1 can be determined from the four tests k_4 is determined by substituting k_1 into (f):

$$k_4 = \frac{(P_1-P_0)}{(x_d-x_c)}-T_1k_1$$

Combining (a) and (c) and rearranging we get:

$$k_2 = \frac{k_4(x_a-x_c)+k_1(T_0x_a-T_1x_c)}{(T_1-T_0)}$$

and thus by substituting k_1 and k_4 we can get k_2.

Then k_1, k_2 and k_4 can be substituted into (a) to get k_3.

$$k_3 = P_0-k_4x_a-T_0k_1x_a-T_0k_2$$

Once the four correction coefficient have been found, these are stored in the EEPROM in the microcomputer 3 and do not have to be recalculated again for the particular sensing element 1 being used.

In order to correct the actual measured pressure, the temperature is measured to enable m and c to be calculated and these values are then used in the equation:

$$P = mx+c$$

to correct the actual measured pressure. As mentioned above, since the rate of change of temperature is typically two or more orders of magnitude less then the rate of change of pressure, m and c need be computed far less frequently than P.

In order to maximise the output voltage swing available from the system, the microcomputer applies coarse offset and gain corrections using the analogue compensating circuitry 4.

This is done using two input/output port lines (Port D2 and Port D3) from the microcomputer. Port D2 is used to programme one of three offsets provided by three resistors 5, 6 and 7, and Port D3 is used to programme one of two gains into the analogue conditioning circuitry.

This is particularly effective with HCMOS microcomputers because the outputs switch to the supply rails and when programmed as an input the leakage is very small. The first programming port line D2 can be programmed as an output and low to inject a positive offset, as an output and high to inject a negative offset or as an input to inject no offset. Thus, taking a pressure transducer with a typical offset of 20mV, the fixed offset compensates for this, if the programmable value is ±10mV. Then instead of allowing for the worst case range of 0-35mV, a maximum of less than 10mV is all that has to be allowed for. The second programming port line D3 is used to select one of two gains. Two amplifiers 8 and 9 are used to provide the gains. When the port line D3 is programmed as an input, the second amplifier 9 is a voltage follower and this provides a gain of 1. When programmed as an output and low, the gain becomes 2. Other gain values, such as 1 and 1.5 for this stage are also possible by appropriate choices of value of components.

It will be appreciated that the invention may be used wherever corrections are required for gain and offset errors by coefficients that can be stored in software. Adjustments are carried out by the HCMOS microcomputer input/output port states. With the basic system only four combinations of pressure and temperature are required to enable the gain and offset correction coefficients to be calculated. If sufficient program space is available within the microcomputer the calculation of the correction coefficients can be carried out internally, producing a complete self-calibration technique. If at a later stage the sensor element is replaced, the only change to the circuit is a software change of the stored coefficients in the EEPROM. Thus no external adjustments are required, either during calibration or under normal operating conditions.

Claims

1. A sensor system comprising one or more sensing elements providing an output signal corresponding to a sensed parameter, means for calculating correction coefficients, a memory for storing said correction coefficients and a CMOS microprocessor for receiving said output signal, for calculating fine trim correction factors for both the gain and the offset of the sensing element(s) using said correction coefficients and for providing a corrected output signal.

2. A sensor system according to claim 1 wherein said memory is an EEPROM.

3. A sensor system according to either claim 1 or claim 2 wherein said CMOS microprocessor is part of an HCMOS microcomputer.

4. A sensor system according to any preceding claim wherein said correction coefficients are themselves calculated by the CMOS microprocessor.

5. A sensor system according to any preceding claim further including compensating means coupled between said sensing element(s) and said CMOS microprocessor for providing a coarse trim of both the offset and the gain of the output signal from the sensing element(s) to the CMOS microprocessor.

6. A sensor system according to claim 5 wherein said compensating means includes means for providing one of a plurality of discrete offsets and one of a plurality of gains, the desired combination of offset and gain being programmed by the CMOS microprocessor.

7. A sensor system according to any preceding claim wherein said sensing element(s) is/are pressure transducers.

8. A sensor system according to claim 7 wherein said correction coefficients are calculated by said CMOS microprocessor from four combinations of measured values of pressure and temperature.

9. A sensor system according to either claim 7 or 8 wherein said compensating means is programmed less frequently than the frequency of pressure sensing by the CMOS microprocessor according to measured values of temperature.

10. A sensor system substantially as hereinbefore described by way of example with reference to the drawing.

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Figure 1